SOLID STEEL CASTINGS

FOR

Ordnance, Structures, and General Machinery,

BY

THE TERRENOIRE PROCESS.

DETAILED SPECIFICATION OF THE MATERIALS, FURNACE PRACTICE, TESTS, ETC.

NOTE.—This Report is printed for private circulation.

A. L. HOLLEY.

NEW YORK, November, 1877.

I TAKE pleasure in stating that the greater part of this Report was compiled by my assistant, Mr. Laureau, from my notes (covering some two weeks' observations) and from his own, and from data which I have since received from Terrenoire. As Mr. Laureau remained a month in Terrenoire after I left, his observations and knowledge of the process became very complete and practical.

Solid Steel Castings.

The most remarkable of the several revolutionary developments of the steel manufacture during the last few years is undoubtedly the production, at Terrenoire, in France, of solid castings, without blow-holes, in *malleable steel*—castings which, after no other treatment than annealing, have the strength, specific gravity, and physical qualities generally, of forged steel. The harder variety, in the shape of shells, goes without breaking through armor-plates which injure chilled-iron shells and even hammered-steel shells in a greater degree, and the softer varieties bend double cold and stretch 25 per cent. and more in tension, like rolled steel boiler-plates.

Two circumstances seem to define the *status* of this improvement—to put it in the list of established rather than of experimental manufactures: 1st. It is the result of no less than ten years' gradual development. Many new processes show spasmodic results of great promise, the essential conditions of which cannot be determined nor maintained in regular practice. This process, on the contrary, like all standard improvements, has been worked out through numerous difficulties, at great cost, and with the constant aid of both chemical and physical analyses.* 2d. The manufacture of solid steel castings, chiefly projectiles, has been carried on regularly above two years, and the process, as finally perfected and formulated, has not been changed during that time. An exact chemical process has been reached and adhered to.

* In July, 1874, as stated in my Report No. 8, First Series: "I saw some test pieces (of steel castings) eight to ten inches square, which were as sound as any iron castings, although malleable."

Immediately after the French Exposition of 1867 a series of experiments were undertaken at Terrenoire, with a view to produce a metal which would meet the requirements of projectiles for naval guns. These experiments led the engineers in charge into a new field of investigations, and resulted in the discovery of a sure and regular method of obtaining steel castings without blow-holes. Sound steel castings cannot now, indeed, be claimed as altogether novel; castings are obtained every day in which blow-holes are nearly avoided. Some Sheffield firms devote themselves almost exclusively to this kind of work, and the Krupp ingots, as shown at several exhibitions, have demonstrated the possibility of producing solid steel castings. But there is between these products and the Terrenoire metal a wide difference: the Sheffield and Krupp castings are melted in crucibles, they are very hard, and, in spite of the long annealing they usually undergo, they show but *little ductility and toughness.* The Terrenoire metal, on the other hand, is produced cheaply in the Siemens furnace, and possesses, in the cast state, all the necessary qualities for industrial and structural purposes: it is soft and malleable, and as strong as ordinary steel of the same grade is after rolling or hammering, and, strange to say, its density is always as high as and sometimes higher than that of ordinary forged steel. These statements, startling as they may be, are supported by facts developed in numerous experiments made by the Terrenoire engineers in developing the manufacture, and by the French Government in testing it.

It is proposed in this paper, 1st, to state briefly the investigations which led to the present result; 2d, a specification of the operation in the open-hearth furnace for both hard and soft steels, including the tests and analyses of the materials employed and products obtained; 3d, illustrations of the process by the details of a number of operations which were witnessed by my assistant and myself; 4th, the operation in the Bessemer converter and in the crucible; 5th, the theory of the process; 6th, some facts about moulds and on annealing; and, 7th, some considerations regarding the uses of solid steel castings.

THE PRELIMINARY INVESTIGATIONS.

There were at the Paris Exposition in 1867 some large projectiles, said to be made of chilled cast-iron, which, it was stated, could perforate thick armor-plates. They came from Gradatz in Styria, and Finspung in Sweden. The French navy tried them, and found that they positively went through the thickest armor-plates then known. Several French works were requested to attempt the manufacture of a similar product, and Terrenoire, among others, started a series of experiments which we will follow in some detail. The problem was an interesting one, inasmuch as up to that time *hardness* and *brittleness* were, as far as cast-iron is concerned, considered as synonymous terms.

One of the first things to be determined was the influence of a metallic mould on cast-iron. For this purpose some cylinders 225 millim. (about 9 in.) in diam. were cast; they were placed between bearings 50 centim. (19¾ in.) apart; a ram weighing 400 kilog. (882 lbs.) was then dropped upon them from different heights. The following are the results of the first experiments:

Description.	Cast in Sand.	Chilled.
Bessèges iron, broke at	13 ft. 1½ in.	4 ft. 11 in.
St. Gervais iron, broke at.............	14 " 9½ "	4 " 11 "

These results were expected, and it was evident that some other and special means had been used to produce these strong projectiles. An analysis of one of them showed the unusually small carbon percentage of 2.94. A low carbon pig had obviously been used as a starting-point, or else the metal had been decarburized by some special process. The Siemens furnace was then brought into use, and a number of different irons were tried with the addition of a certain amount of steel-scrap before casting.

The following drop-tests were obtained from the 882-lb. ram, supports 19¾ in. apart:

Description.	Cast in Sand.	Chilled.
Charge No. 622—1,500 lbs. Terrenoire iron, with 600 lbs. scrap......................	18 ft.	11 ft. 5 in.
Charge No. 832—1,500 lbs. St. Gervais iron, with 600 lbs. scrap......................	15 ft. 7 in.	8 ft. 2 in.
Charge No. 688—1,500 lbs. Givors iron, with 600 lbs. scrap	13 ft. 1½ in.	9 ft. 10 in.
Charge No. 879—1,500 lbs. Givors iron, with 600 lbs. scrap..........	13 ft. 1½ in.	18 ft.

These results showed that the addition of scrap improved the iron when either cast in sand or chilled.

But while these experiments gave important information regarding the problem in hand, they also opened the way to the manufacture of solid cast-steel. The considerable variation in the breaking-points of the different test pieces, after careful consideration, was found to correspond with the amounts of silicon they contained; the strongest invariably contained the largest amount of silicon. Charge 832, which shows a weak chilled test, is made of St. Gervais pig, in which almost no silicon is found. The Givors pig used in Charge 688 contains only 1.36 per cent. of silicon, while the iron used in 879 contains 3.22 per cent. Numerous other experiments showed that these results were regularly obtained, and that the strength was always in proportion to the amount of silicon in the pig.

It was further ascertained that when the addition of scrap was pushed beyond a certain limit, bubbling (and hence blow-holes) began to appear, and that the time of the bubbling varied with the proportion of silicon in the pig. This discovery was a very important one; it gave a clear idea of the action of silicon, so necessary in the manufacture of steel without blow-holes. After a number of careful experiments, some projectiles made of this mixed metal were sent to Gâvres and subjected to trial. On the 13th of December, 1869, two 9½-in.

solid projectiles were fired at a 6-inch armor-plate at a speed of 1,036 ft. per second. They went through the plate without any deformation whatever. On January 18, 1870, a trial was made with 9-in. shells. They were fired at the 6-in. plate with a speed of 1,040 feet, and they went through the plate as well as the solid projectiles had done. These trials, though satisfactory in themselves, were not conclusive; the Commission insisted upon testing the projectiles in oblique firing, which was done on the 19th of April, 1870. Two 9½-in. solid projectiles were fired at a 6-in. plate standing at an angle of 20° from the perpendicular, but were broken. Subsequent trials gave the same results. When a solid projectile is used, it does not matter much whether it breaks or not, as long as it goes through the plate; but a shell should go through whole and burst on the other side. The problem was therefore unsolved, and the Terrenoire engineers clearly saw that their mixed metal could not answer.

They then resolved upon producing a cast metal hard enough not to be deformed by the blow, and ductile enough not to break; in other words, a *real steel.* Their previous experience had shown the action of silicon; they were convinced that the more siliconized a pig is, the larger amount of scrap it will bear before the special state of oxidation occurs which produces blow-holes. Guided by this knowledge, they used for the initial bath a pig containing more than 8 per cent. of silicon and some manganese. They succeeded by this method in obtaining a fair product, but it lacked uniformity, as it was very difficult to get a true idea of the composition of the bath at the end of the operation.

It then occurred to them that the most rational method would be to follow the regular Martin practice, by decarburizing an initial bath to the required point, and then correcting the oxidation by silicious pig. After a good many preliminary failures they finally determined that, in order to obtain steel without blow-holes, a proportion of 11 to 12 per cent. of a pig containing 3.5 to 4.0 of silicon should be added. This proportion should vary according to the degree of hardness required. The product was regularly without blow-holes, and

gave the following tons' resistance per square inch in the testing-machine :

	Raw metal.	Tempered in oil.
Elastic limit............	19.68 to 20.95	37.10 to 40.27
Breaking load..........	30.48 to 31.50	46.45 to 50.8
Stretching...	1.5%	0.20 to 0.30%

These results indicate a very hard metal, unfit for most uses except projectiles. The experiments had taken so much time that no firing trials were made until July, 1872. Then two unannealed 9½-in. projectiles were fired at an 8-in. plate. They went through without breaking, but the rounded part was upset from 1¼ to 1½ inch. The cylindrical part was unchanged. These results, though encouraging, did not seem sufficient, and new experiments had to be made in order to obtain a metal which, though a little harder, would be less deformed by the blow.

The process, too, was unsatisfactory ; the metal was pasty, it ran very badly, and did not stand forging very well. A special study of the question showed that this pasty state of the metal was due to the addition of silicious pig. The silicon, in being oxidized to silica, prevented the formation of carbonic oxide and blow-holes ; but this silica, in presence of so much iron, formed silicates, which to a great extent remained in the bath. Hence the lack of fluidity as well as the inferiority of the metal ; the interposed slag must necessarily decrease its strength and ductility.

The cause of the defect once known, the remedy determined upon was the final addition of some substance which would make the slag sufficiently fluid to separate from the metal. Manganese was found to be the right material, not only on account of the fluid slag it forms, but also on account of the qualities it imparts to the steel.

The final improvement was the introduction of a certain amount of manganese in the *initial* bath, the function of which is to keep down oxidation from the start, for the following

reason : If oxygen is allowed to go on accumulating in the bath, it is impossible to tell how much there is of it present when the final additions of silicon and manganese are made, and how much of these substances will be removed in taking up this oxygen. Therefore oxygen must be kept out, so that the whole of the ingredients finally added shall be left to perform their work.

All these modifications were the work of years ; it was not until 1875 that the Terrenoire Company reached their aim—the production of a cast-steel shell * which should go unharmed through an armor-plate and burst on the other side. On September 24, 1875, two 9½-in. shells were fired normally at an 8¾-in. armor-plate, and another shell of the same size was fired at an angle of 20° at an 8-in. plate, with a speed of 1,280 ft. The three shells went through and were found respectively at the following distances behind the blocking : 710 ft., 895 ft., and 2,060 ft. The rounded ends were compressed from ¼ to ½ inch. On January 8, 1876, three 9½ shells were fired at angles of 28° and 30°. The plate was 8 inches thick and the initial speed 1,390 ft. The three projectiles perforated the plates and were found behind the blocking at the following distances : 1,302 ft., 2,952 ft., and 3,608 ft. Two of these shells were compressed about ½ in., and showed a swelling at the circumference of ¼ in. ; the third one, made purposely of a softer metal, was compressed 1¼ in. and bulged out ⅜ of an inch. These were perfectly satisfactory results, for the inside chamber was of the regulation size, and firing had been tried at a maximum angle.

Had the Terrenoire engineers stopped their investigations at this point, and produced a metal fit only for the manufacture of projectiles, their discovery could not have been considered, from an industrial standpoint, as of the highest importance. But, following up the line of experiments, they succeeded in producing all varieties of steel castings without blow-holes, from very soft to very hard, as surely and regularly as ingots are made.

* An engraving of the Terrenoire shell is appended. It is cast solid and bored out. The chamber is plugged with steel of the same kind.

The chemical and mechanical qualities of the perfected metal are shown in Table A, and also in the large table at the end of this Report. In the latter the results of annealed and oil-hardened metal only are given. In Table A the results of raw, annealed, and hardened metal are stated, and from this table we derive the following facts:

1st. That the chemical composition of this metal is widely different from that of ordinary steel.

2d. That its average tensile resistance in a cast and annealed state—which we shall afterwards observe to be the normal state of steel without blow-holes—is as follows:

Hard	Steel,	47.51 tons per sq.	in. and	8.1%	elongation.
Medium	"	46.92 "	"	14.6%	"
Soft	"	31.72 "	"	25.3%	"

This is fully up to the standard of hammered Siemens-Martin steel.

These remarkable averages do not bear on a few experimental heats only, but on a whole series of operations made in the regular practice at the works, and for commercial purposes.

TABLE A.

Strength of Solid Steel Castings, Raw, Annealed, and Hardened.

Description.	Analysis.			Raw Metal.			Annealed Metal.			Metal cooled suddenly and slightly Annealed.		
	C.	Si.	Mn.	Elastic Limit.	Breaking Load.	Elongation.	Elastic Limit.	Breaking Load.	Elongation.	Elastic Limit.	Breaking Load.	Elongation.
Hard Metal:												
Charge No. 1197.	0.635	0.55	0.95	20.25	33 14	1.20	23.17	49.84	7.0	34.92	73.66	0.7
" " 1204.				15.04	35.56	2.10	18.66	46.35	7.5	27.21	70.80	1.0
" " 1211.	0.55	0.405	1.05	16.06	36 83	4.0	16.06	46.35	9.8	18.28	49 02	6.5
Medium Metal:												
Charge No. 1543.	0.425	0 275	0.75	20 95	36.76	2.0	22 09	47.49	12.2	23 24	47.75	11.5
" " 1558.				19 81	39.68	3.3	23.46	46.29	14.0	24.76	48.76	12.0
" " 1565.	0.45	0.35	1.10	19.55	37.97	2.8	21.59	46.99	17.5	28.57	53.97	8.0
Soft Metal:												
Charge No. 2078.	0.26	0.26	0.41	12.23	29.71	12.8	14.92	31.24	28.5	19.87	35.87	17.5
" " 2262.				10.92	30.35	13.8	12.19	29.52	26.5	19.74	34.92	22.8
" " 18.	0.317	0.30	0.48	11.49	36.06	14.8	12.82	34.41	21.5	22.54	42.98	11.0

OPERATION IN THE OPEN-HEARTH FURNACE.

The operation, as may have been gathered from the preceding pages, consists:

1st. In the formation of an initial bath of manganiferous pig to prevent oxidation during the process.

2d. In dissolving such softening or decarburizing materials as wrought-iron in this bath.

3d. In the addition, at the end of the operation, of silicon and manganese in such order and proportion as to prevent the formation of blow-holes while casting, and at the same time give to the steel its special physical qualities.

Another very important feature of the process is the method of taking tests.

HARD STEEL.

We will now describe in detail the different stages of the operation, and we will suppose at first, so as to avoid confusion, that the metal to be produced is of the harder kind.

The Furnace.—The object of greatest importance during the whole of the operation is *to keep oxidation as low as possible in the bath.* For this reason the furnace must, indeed, be kept as hot as possible, with a good solid body of flame; but there must be only just enough air admitted to promote thorough combustion.

The Initial Bath.—This must be made of pig iron containing from 6 to 8 per cent. of manganese. Spiegeleisen is probably the most convenient form of pig; but, as a spiegel with this percentage may not be at hand at all times, the bath may be formed by taking a richer spiegel, say 12 or 14 per cent. manganese, and diluting it with one-half ordinary pig containing no manganese. These mixtures can be made of any kind of spiegel or ferro-manganese. If we suppose, for instance, that the initial bath must be 600 lbs., and the only spiegel on hand is 18 per cent., by using 200 lbs. of it and 400 lbs. of ordinary pig the bath will be brought down to its right point.

In some cases the greater part of the bath should be made

of pig poor in carbon—as, for instance, when particularly highly carburized materials are to be dissolved in the bath.

The weight of the initial bath, in proportion to that of the whole charge, varies according to the conditions under which the heat is made. We may say, generally, that 11 per cent. of the whole is an average quantity. Every open-hearth melter knows that it is impossible to determine in advance the exact quantity of pig wanted for the operation. The temperature of the furnace has much to do with it. If it takes too long to melt the first charge, a great deal of the carbon will be carried away, and, in this case, it will be necessary to add pig at a later stage. The nature of the refining material has also a great influence. If a specially pure product is required, and the softening materials used are very fine puddled blooms nearly free from carbon and manganese, the initial bath must necessarily be larger, as well as richer in manganese; it may in this case reach 14 per cent. of the whole charge.

The materials for the initial bath are always charged cold. The pigs are spread on the bottom, so as to hasten their melting by exposing them to the direct action of the flame. At Terrenoire the first charge averages about 1,200 lbs., and is melted in an hour.

When large pieces, like mould-fountains or ingot-ends, are to form part of the refining material, they are put in cold with the spiegel; they are placed on the bottom, and the spiegel is spread over them, so that it will melt first. This method, though accompanied by some oxidation, is thought economical in the long run, as these heavy pieces heat more quickly in the melting-furnace than in the auxiliary. It takes about four hours to melt a mixed charge of this kind weighing 3,500 lbs.

The Softening or Refining Materials.—Soon after the bath is completely melted the refining materials are successively added, in small lots of about 450 lbs. each. These are invariably pre-heated, as charging them cold and frequently would tend to keep down the temperature of the bath. When the initial bath consists of a small quantity of spiegel only, it is well to make the next charge small enough to be covered en-

tirely by the bath, in order to avoid oxidation. The materials must be dropped in front of the doors, at the deepest part of the hearth, and, if the pieces are covered by a thick film of oxide, it is well to shake or scrape it off before charging. The usual time for melting one of these lots is twenty minutes. Pre-heating is employed, not only to keep the furnace hot, but to save oxidation—to furnish an opportunity to remove oxide before charging. The Terrenoire Company have never tried to melt the charge all at a time; they have feared that too long an exposure of the bare metal to the flame would oxidize it beyond redemption. The latest form of Pernot furnace, however, melts a 6-ton charge in three hours, the whole being charged at once and cold. This is even less time than required to melt an initial bath of 3,000 pounds at Terrenoire.

The materials used in this second period of the operation are chosen with reference to the quality required in the finished product. They may be good Bessemer or open-hearth scrap, fountains from previous castings, puddled bars, or direct blooms. Materials inferior to these would correspondingly lower the quality of the product. For projectiles the Terrenoire Company generally use Bessemer ingot and rail ends, with fountains from previous projectile charges. These are all pretty high in carbon and contain some manganese. This is the reason why such a comparatively small initial bath is required. The proportion of refining materials to the whole charge averages 78 per cent.

As soon as a charge is melted another is added, and so on, until the operator thinks the time has come to assure himself of the state of the bath. A series of tests then commences.

Slag Tests before the Final Additions to the Bath.—Spiegeleisen is used for the initial bath, because the manganese it contains, being the most oxidizable of all the materials present, will remove oxygen that may be present in the bath, and will intercept oxygen that tends to enter it. So that, the more manganese there is in the slag, the less oxygen there will be in the metal below. If, then, the amount of manganese in the slag can be readily determined, there is constantly present

a delicate test of the oxidation of the bath. Oxide of iron tends to make the slag black; manganese turns it light olive or ash-green; and the different tints between these two extremes give to the practised eye an exact idea of the state of the oxidation of the bath.

To take a slag specimen, the workman thrusts into the furnace a flat iron bar (about $1\frac{1}{2}$ by $\frac{3}{8}$ in.), and, clearing away the top slag, moves it about in the under layer. The rod is quickly removed; the slag is knocked off as soon as it sets, and is then allowed to cool. As the film is only from $\frac{1}{16}$ to $\frac{1}{8}$ in. thick, this takes but a minute or two. The fracture of this film of slag reveals its color and texture.

The manganese does not especially show in the slag during the first two or three hours of the operation, but its presence becomes noticeable by the rapid change which takes place after about a third of the scrap is charged. From black and porous the slag turns green and vitreous. At first the whole thickness of the specimen is of the same color, with the exception of the very outside, which becomes oxidized by contact with the air. The fracture at that time resembles that of light olive-green glass; but this appearance soon changes as the oxidation goes on. The outside of the specimen, already oxidized in the furnace, shows a thicker film of black oxide, while the olive green of the inside deepens into a darker one. In most cases there appears on the inside—the side next the rod—a well-defined, light streak, with another darker one next to it, and, finally, the black outside streak. These shades do not die into one another, but stand side by side in well-defined strata. As the additional materials are charged, the streaks grow darker and darker; the outside remains black, but the central part becomes brownish green, somewhat resembling dark bottle-green cloth, and the inside streak deepens into a dark pickled-olive green. Sometimes, and especially when nearly all the scrap is added, the fractured slag shows the dark bottle-green cloth color throughout. This is as deep as it should be allowed to go, as at this point very little of the manganese remains in the bath, and the safety of the operation is endangered. Even if the slag should become quite black—and this will happen

under some circumstances—the bath can be saved by adding a small quantity of manganese, in the shape of a rich ferro-manganese; 22 lbs. of 50-per-cent. ferro-manganese is a usual dose, and has generally the desired effect. Although the slag does not quite recover its greenish color, it becomes perceptibly lighter. It is only when the slag assumes a spongy, rotten appearance that the bath may be said to be beyond redemption; the oxidation is then such that it is impossible to determine the exact amount of silicon and manganese necessary to reduce it. But this is an exceedingly rare occurrence, and there is no record of its having happened since the regular manufacture of steel without blow-holes has been started. When it did happen during the experimental period, the bath was treated, as in the ordinary Martin operation, by the addition of spiegel or ferro-manganese, and ordinary ingot-steel was made. This can always be done in case of any mishap.

Hammering and Cold-bending Tests before the Final Additions.—The slag test gives no indication of the physical state of the metal, which is an equally important guide in the operation. When, therefore, the operator has reason to believe that the metal is approaching the point of sufficient softening or purification, he makes the following tests: A ladleful of metal is taken from the furnace and cast into a round ingot about 3 in. in diameter and 1¼ in. thick. The ingot is knocked out of the mould as soon as set, and flattened under a special steam-hammer, at its original heat, into a disk about 6 in. in diameter and ⅜ in. thick.

This method of taking tests has many advantages which recommend it to all practical steel-makers. It gives an excellent opportunity to judge of red-shortness, and the test-piece is of sufficient size for cold-bending. The system is rapid, convenient, and accurate, and it furnishes a comparative scale much safer than the mere fracture of a very small ingot.

No tests are taken until all but two or three of the softening-charges have been added. The flattened disk at this stage of the operation shows starred edges, and sometimes deep radial cracks 1½ to 2 inches deep.

All test disks are prepared for cold-bending by being cooled

in the air three or four minutes, till they are black-hot, and then completely cooled in soap-water. The disk is bent to show its softness; if taken before the last charge but one, it will usually bend about 1½ in., and break. One taken before the last charge would show little improvement in the hammering, but would bend to an angle of 45°. A test taken after the last charge would hammer about like the others, but it would bend until the folds were ½ or ¾ in. apart, and, if doubled up flat under the steam-hammer, would crack clear across, yet without breaking off.

It happens sometimes that a charge threatens to become too soft; the test taken before the last two charges may bend a little too much, showing too great decarburization. The remedy is the same as in the ordinary Martin practice, and consists in adding spiegel—the amount, of course, cannot be definitely stated; it is determined by an expert examination of the tests.

If, on the other hand, the tests prove too hard, an additional charge of softening material should be made. Puddled blooms might be substituted for steel scrap, if the latter had formed the charge.

After the last softening charge has been added (in case the finished product is to contain about 0.55 carbon) the test ingot, hammered to a ⅜-in. thick disk, should have a number of small cracks, from ⅛ to ¼ in. deep, all around the edges, and perhaps two or three deep radial cracks from 1 to 2 in. deep; it should bend without breaking until the folds are from ½ to 1 in. apart, and, when brought to a close fold under the steam-hammer, a crack should be seen clear across the bend. Any very great deviation from this result will announce a disturbance in the bath, and suitable steps to remedy it should be taken at once.

It often happens that the metal tests prove soft enough when the slag is yet very light. This occurs, in a thoroughly well-going furnace, when the oxidizing influence of the flame is reduced to a minimum. The manganese burns slowly, and is insufficiently removed when the carbon has been brought down to the right point by the refining materials. In this

case the amount of manganese introduced with the final additions is reduced in a manner proportionate to the color of the slag. The same result might be obtained by leaving the charge in the furnace long enough for the manganese to burn away; but some of the carbon might also escape and make the metal too soft, which defect could be remedied only by a further addition of spiegel, causing expense and loss of time.

It will be seen that by means of the tests above described the operator can judge of the state of his metal with great nicety, and has at hand all the necessary elements to remedy any unfavorable tendency likely to develop during the operation.

When satisfactory tests have been obtained, after all the above-mentioned materials have been charged, the operation is allowed to go on undisturbed for some time, so that the bath may store up heat enough to ensure thorough fluidity while casting, as well as a rapid incorporation of the ingredients introduced with the final additions. It is during this heating period that the slag tests become specially important. The aim is to burn away as much manganese as possible without oxidizing any iron. The manganese in the original bath is to be consumed, in order that the definite quantity of this material added just before casting may do its definite work; and yet it must not be quite consumed until the moment of the final additions, otherwise the bath will become oxidized. When the furnace is very hot, and the slag has reached the proper color—which varies between a dark pickled-olive green and a darker greenish brown—the bath is in a condition to receive the final additions.

The final additions.—These consist of a special pig, containing both silicon and manganese, and also an additional quantity of manganese introduced in the shape of a 50 or 60 per cent. Mn. ferro-manganese. A part of these ingredients is taken up by reactions which prevent the formation of blow-holes; the remainder is left in the metal to impart to it the physical qualities shown in Table A. The usual charge consists of 11 per cent. of special pig, having the following composition:

Mn	3.50
C	3.00
Si	4.20 to 4.60
P	0.10

If the special pig contains less than 4.50 of silicon, 12 per cent. should be added. Ferro-manganese also is employed, because the special pig, as at present made in the blast-furnace, does not contain enough manganese. The proportion of 50 to 60 per cent. Mn. ferro-manganese used varies from 1 to 1.3 per cent. of the total charge. In particular cases the amount must be decreased—as, for instance, when the slag is greener than usual before the final additions; expert practice must be the guide in this case.

The special pig is charged hot. While it is melting a marked change takes place: the bath, which up to that time had bubbled about as much as in the ordinary pig and scrap operation, becomes gradually more and more quiet, until its surface is smooth and scarcely broken by small and widely-scattered bubbles. When the special pig is nearly all melted the ferro-manganese is thrown in hot. The bath is then rabbled vigorously for about a minute, and casting takes place immediately.

Final metal tests.—While casting is going on a few more tests are taken, so as to get a definite idea of the quality of the finished product. The test ingot is hammered just as soon as it comes out of the mould, without reheating. The resulting disk has smooth, rounded edges, but is, of course, much harder than the previous disks. After having been allowed to cool in the air, the disk is placed flat on a hollowed block, so that the edges only bear. It is then struck in the centre with a 20-lb. sledge swung clear around. Three test disks are generally broken at the end of each charge, and the average number of blows gives a pretty good idea of the quality of the metal. Four blows are considered a good average, and the permanent bend should not be more than ¼ inch; less bending proves the material too brittle; more bending proves it too soft.

These final tests might, at first sight, appear unnecessary;

the metal is cast and nothing can change its nature in the moulds. While this is true of ordinary steel, it must be remembered that this metal has to be annealed before it is used. If, therefore, the final test pieces show a deviation from the accepted average, all castings belonging to that charge are followed to the annealing-furnace and heated a shorter or longer time, according to the characteristics developed by their tests.

In addition to the breaking of these disks, a test ingot is usually broken under the steam-hammer. It is placed on a short piece of double-headed rail resting on the anvil; a piece of ⅜-in. square steel is laid upon it and the hammer is dropped at full stroke. This is a check on the disk test, and it also shows the fracture very well.

In practice, the test ingots are never reheated. It might, in particular cases, become necessary to do so, but the knowledge thus derived adds very little to what can be learned from a direct test. We did reheat and hammer some ingots; before the final additions the disks cracked less on the edges and bent a little better; the final tests seemed a little more ductile, but the malleability was not improved.

In general it may be stated that this steel is not improved by hammering, nor is it injured; it may often be important to draw down some parts of a casting.

Casting.—At Terrenoire, in the old shop where this manufacture is carried on, the metal is tapped directly from the furnace into the moulds. There are two tap-holes, side by side, running into one spout fitted with two nozzles. If one of the holes gets stopped the other is opened (see my Report No. 8, page 28, First Series). The moulds stand on a truck moved by a windlass at each end of a long trench-like casting-pit directly in front of the furnace. It is useless to state that this is a very objectionable way of casting. It never takes less than fifteen minutes to run a charge out of the furnace when everything goes smoothly, while, under the most favorable circumstances, the steel running between the moulds as they are brought successively under the nozzle makes a great deal of scrap. But despite these disadvantages the manufac-

ture has been going on for several years without serious accident. This is probably due to the perfect quietness of the metal; it runs into the moulds without any splashing, and no escape of gas is noticed during the whole casting operation. The steel settles dead and level in the fountains, and the covers, laid loosely on the sand which is thrown upon the metal, are never disturbed. It is evident, however, that this special steel is not quite as fluid as ordinary steel having the same percentage of carbon. This is due to the presence of silicon. Hence, as before mentioned, a very hot furnace is indispensable.

SOFT STEEL.

The composition of the charge and the nature of the tests in the manufacture of soft steel differ in some essential points from the description above given.

The Initial Bath.—As the additional materials for a soft charge are poorer in carbon than those for a hard one, an equal amount of the former will refine a larger amount of pig. For this reason the weight of the initial bath is 14 per cent. of the total charge, instead of 11 per cent. These materials, unlike Bessemer rail-ends and fountains, contain little or no manganese; it becomes, therefore, necessary to increase the proportion of this ingredient in the bath, so as to keep the slag good to the end. Experience has proved that a 12 per cent. spiegel will accomplish this object. The bath may be made in various ways, and of different mixtures, as described for hard steel, so that the proportion of manganese is kept right.

The furnace should be kept, if anything, hotter than for hard steel, because, the proportion of carbon being reduced, the metal, while casting, will otherwise be less fluid, and will tend to chill in the nozzle and tap-hole. When the pig is all melted, it is well to wait a few minutes before adding anything more, so as to get the bath as hot as possible.

The Refining Materials.—These must consist of highly decarburized iron, and should be as free as possible from phosphorus. Blooms puddled from good Bessemer pig are

generally used, and occasionally soft-steel scrap of fine quality. These materials are pre-heated to a bright red and charged in lots of about 450 lbs. They are well shaken and scraped before being put into the bath, so as to remove the oxide with which they are coated. As soon as a charge is melted another is added, and so on until all but two or three are in. A set of tests is then made. Puddled blooms are a little harder to melt than rail-ends. It usually takes a full half-hour to thoroughly melt a 450-lb. charge. The blooms must be dropped in the middle of the furnace, at the deepest part of the bath, so as to be covered by it.

Tests before the final additions.—Both slag and metal tests are taken in the manner before described. The slag fractures should not vary much from those for hard steel, except that they may be a shade darker. Since the product must be purer, and poorer in carbon, manganese, and silicon, these substances should be pretty well eliminated before the final additions are made, provided, however, that oxidation is not allowed in the bath. A black slag, although vitreous and clear, would require the addition of ferro-manganese; but if the slag is yet too light after blooms enough are put in to bring the charge to the desired weight, the bath must be left undisturbed until the color has reached the proper shade.

The hammered disks should be somewhat smoother and much softer than hard-steel test pieces. Usually the edges are rough and serrated, but the large radial cracks are fewer and shallower. In appearance the soft-steel disks are intermediate between the hard-steel disks before the addition of special pig and the corresponding finished steel disks. The metal has reached the right point when the forged disk bends to a close fold under the steam-hammer without cracking at the back of the bend. For very soft metal these disks should double up again to a four-fold piece with a little cracking in the centre. The metal tests previously described, and those just above mentioned, may be taken as the extreme limits of the scale between which all degrees of hardness have as yet been produced.

If the tests prove the metal too soft, spiegel is added; if too hard, after the full weight is charged (and this, as before stated, happens in connection with a light slag), the manganese and carbon are given time to burn away before the addition of special pig.

It is well at any rate to give the bath time to get hot at this period, and the final additions should be made only when the slag threatens to become too dark.

The final additions.—These consist of a special pig of the following composition:

C.	1.60
Mn.	14.00
Si.	7.50
P.	0.125

Such a pig is made and used at Terrenoire, but a pig containing the indicated proportion of silicon and no manganese could be substituted, the proper amount of the latter ingredient being introduced in the shape of a very rich ferro-manganese—the only difficulty is the greater addition of carbon by this method.

The usual proportion of this special pig is 3½ to 4 per cent. of the charge already introduced, depending somewhat on the percentage of manganese required in the product and on the appearance of the slag. In general, there should be about 0.80 per cent. of manganese introduced, in order to leave about 0.60 per cent. in the finished product. When as high a percentage as this is wanted, it is necessary to make a still further addition of ferro-manganese, which must be rich, say not less than 75 per cent. Mn. When a low percentage of manganese is required in the finished product—0.40 and below, for instance—that introduced with the special pig is sufficient.

The special pig is pre-heated to a bright red and charged when the bath is very hot. If ferro-manganese is used in addition, it is thrown in when the pig is nearly all melted. The furnace-man feels with his rabble to make sure that everything is melted; he then stirs the bath vigorously for about a minute, and casting takes place immediately.

Casting is done as described above. The steel is not very

fluid. It gathers a little around the nozzle, and the solidified particles must be removed by a carefully-handled bar, in order to prevent the closing of the hole; but with this precaution there is little difficulty. The use of a ladle would allow more rapid casting, and so largely avoid chilling.

Tests while casting.—These are taken exactly as described above, but they show a much softer material. When hammered they look very much like hard-steel tests, but, instead of breaking with a few blows, they bend without cracking until the folds are ¾ inch apart, and when brought together under the steam-hammer a wide crack will show clear across the disk, although the pieces will not fall apart. The metal shows a much coarser grain than hard steel. When a test ingot is broken whole under the hammer, as described above, it requires three times as many blows to start a crack, and additional pounding to tear the pieces apart. The fracture in this case shows a strong-grained metal, the ductility of which is proved by the marked deformation it bears before breaking.

ILLUSTRATIONS OF THE PRACTICE.

In order to give the steel-maker a still better idea of the practice, we will now describe several operations which we witnessed at Terrenoire in the early part of 1877.

Charge 127, *February* 27.

In this charge no disturbance of normal conditions occurred. The times of charging and test were as follows:

At 7.10 A.M. initial bath, 1,320 lbs. 7 per cent. Mn. spiegel.

At 7.10 A.M. " 2,178 lbs. fountains from previous heats. The fountains were charged first and well spread on the bottom. The spiegel was placed upon the fountains, the whole being cold. The furnace being very hot, the spiegel was melted at 8.30; but the fountains melted much more slowly, and not until 11.05 was the whole charge fluid.

At 11.20, 440 lbs. of Bessemer rail-ends were charged at a bright-red heat, care being taken to shake off the oxide adhering to them.

At 11.40, 440 lbs. Bessemer rail-ends charged.

At 11.55, 440 lbs. Bessemer rail-ends charged.

At 12.15, 448 lbs. Bessemer rail-ends charged.

At 12.30 a preliminary slag test was taken. The fracture showed a light-green color interwoven with darker streaks; it somewhat resembled certain varieties of malachite.

At 12.37, 440 lbs. rail-ends charged.

At 1.00, 448 lbs. rail-ends charged.

At 1.15, 440 lbs. rail-ends charged.

At 1.20 a second examination of the slag showed it much darker than the first test. The outside film was quite black; the streak nearest the rabble was yet light, while the intervening space had deepened to a pickled-olive green.

At 1.40, 440 lbs. rail-ends charged.

At 2.00, 440 lbs. rail-ends charged.

At 2.20, 440 lbs. rail-ends charged.

At 2.30 the first steel test was taken. The edges cracked considerably all around; there were four large cracks ranging from ¾ to 1½ in. deep. The disk bent to an angle of 60° and broke. The fracture showed a very fine-grained, steely metal. The slag test taken in connection with this metal test was much darker than the preceding one. The light streak had disappeared, and the black outside film was a little thicker than before. It was decided that the bath would bear another charge of rail-ends.

At 2.40, 440 lbs. of rail-ends charged.

At 2.50 a second steel test was taken. The edges of the disk were less rough, and three large cracks only were seen, one of them being about 1¾ in. deep. The disk bent until the folds were within ⅜ inch apart, and when hammered flat cracked clear across, but the pieces hung together. This was considered a good test. The slag specimen taken in connection was very nearly the same as the previous one. The bath was allowed to heat for some time.

At 3.00 a slag test was taken; the fracture was clean and vitreous, and the color gradually shaded from black on the outside to pickled-olive green on the inside. It was thought that the oxidation had reached the limit.

At 3.07, 910 lbs. of special pig were added at a bright-red

heat. This was very nearly eleven per cent. of the charge already in the furnace. At 3.15 it was ascertained by feeling with a rabble that the pig was very nearly melted. It is well known that when scrap or ordinary pig are thrown into an open-hearth bath, there is a continual bubbling immediately above the place where they are placed. No such phenomenon occurs with this special pig; on the contrary, during the whole previous part of the operation the bath bubbles about as much as in any pig and scrap charge when good materials are used, but as soon as the silicious pig begins to melt, this bubbling gradually ceases, until, at the end of the operation, the bath is quite still and smooth.

At 3.17, 139 lbs. of 50 per cent. Mn. ferro-manganese were charged hot. The bath was immediately rabbled, so as to aid the mixing and reactions.

At 3.20 casting took place. While casting was going on, three test ingots were taken; two were hammered to disks which broke respectively at 7 and 2 blows of the sledge; the third ingot broke at 2 blows (the usual number) of the steam-hammer, thus showing a very good average.

The time occupied in melting the charge was 8 hours 10 minutes, which is about the average.

The composition of the charge was as follows:

7% Mn. Spiegel..........	1,320 lbs., or 14%	of the whole charge.
Refining materials......	7,034 lbs., or 74.8%	" "
Special pig.............	910 lbs., or 9.8%	" "
Ferro-manganese, 50% Mn.	139 lbs., or 1.4%	" "
Total...........	9,403 lbs. 100%	

The proportions of the different ingredients introduced by the final additions are:

Carbon in special pig......	27.3 lbs.	or 0.42%
" in ferro-manganese	7.64 lbs.	
Silicon....................	41.86 lbs.,	or 0.50%
Manganese in special pig	31.85 lbs.	or 1.22%
" in ferro-mang.	70. lbs.	

The percentages given above are in relation to the amount charged before the final additions.

The quantity of carbon left in the bath before the final addition amounted probably to 0.30 or 0.35 per cent.; the

quantity of silicon was reduced very nearly to nothing, and the manganese was below 0.15; so that, after the reactions had taken place, the final product would retain a chemical composition similar to that of the hard metal in Table A.

The whole charge was cast into projectiles for the French navy.

Charge 123, *February* 20.

This charge was a little irregular in its behavior.

At 9.30 A.M. initial bath, 880 lbs. 7 per cent. Mn. spiegel.
" " 2,288 lbs. steel fountains.

Both were charged cold, the fountains being spread on the bottom and the spiegel on top.

The furnace worked rather slowly for the first hour, but gradually improved, until it got into first-rate condition, with a solid body of non-oxidizing flame.

At 1 o'clock 440 lbs. of Bessemer rail-ends were well cleaned of oxide and charged at a bright-red heat.

At 1.20, 440 lbs. of Bessemer rail-ends were charged.
At 1.45, 440 lbs. " " "
At 2.05, 440 lbs. " " "
At 2.30, 440 lbs. " " "
At 2.45, 440 lbs. " " "
At 3.05, 440 lbs. " " "

At 3.15 the first slag test was very light green throughout.

At 3.20, 440 lbs. of Bessemer rail-ends were charged.
At 3.45, 440 lbs. " " "
At 4.10, 451 lbs. " " "

At 4.25 the slag was yet light, differing only from the previous specimen in having a few dark streaks.

At 4.30, 448 lbs. of Bessemer rail-ends were charged.
At 4.50, 440 lbs. " " "

At 5.15 the first test ingot hammered into a much cleaner disk than usual; the edges were tolerably smooth, and there were only two noticeable cracks, the deepest about ¾ inch; but it broke after about 1½ inch deflection. The corresponding slag test was light yet, though a little darker than the others. The presence of much manganese in the bath explains the better hammering of the test ingot. The metal was

certainly too hard, and, as it was necessary to limit the charge to a certain weight, it was decided to use puddled blooms instead of rail-ends, in order to bring it down more rapidly. It seemed as if the furnace had no tendency to oxidize, and that refining took place by dilution only.

At 5.35, 253 lbs. of puddled blooms were charged.

At 6.10 a metal test hammered well, and, although a little hard, it bent double with the usual crack clear across, but without breaking apart. The corresponding slag test was, like the 5.15 test, very light, the black film having hardly appreciable thickness. But, as the metal was good, it was decided to introduce the final additions and decrease the quantity of manganese in a manner corresponding to the color of the slag.

At 6.35, 968 lbs. of special pig, representing about 11 per cent. of the weight already charged, were introduced, at a bright-red heat.

At 6.37, when this pig was almost or quite melted, 106 lbs. of 50 per cent. Mn. ferro-manganese were charged hot. The bath was then thoroughly rabbled, and casting took place at 6.40 P.M. Three test ingots, taken while casting, were hammered into disks and broken cold respectively with 8, 7, and 2 blows of the hammer.

The time of the heat was 9 hours 10 minutes.

The whole charge was as follows:

7% Mn. spiegel...........	880 lbs., or	9.4	per cent. of the whole charge.
Refining materials........	7,440 lbs., or	79.2	" " "
Special pig..............	968 lbs., or	10.3	" " "
50% Mn. ferro-manganese..	106 lbs., or	1.1	" " "
Total.............	9,394 lbs.	100.00	

The quantity of the different ingredients introduced with the final additions, and their proportions in relation to the amount previously charged, were as follows:

Carbon in special pig..............	29.04 lbs.,	or 0.40 per cent.
" ferro-manganese........	5.83 lbs.,	
Silicon..........................	44.52 lbs.,	or 0.51 "
Manganese in special pig...........	33.88 lbs.,	or 0.99 "
" ferro-manganese.....	53.00 lbs.,	

These proportions were much the same as in the previous charge, excepting that less manganese was put in, an unusually

large amount of it having remained in the bath before the final additions. Of course no rigid rule for such additions can be given; practice soon becomes a reliable guide. In this case the operator did not miss the mark, as the tests stood the average number of blows.

The whole charge went into one casting—a brace for a large gun-carriage. The pattern was rather intricate, with thin ribs and cores hard to hold; but the piece came out quite as good as any ordinary cast-iron casting. It was considered a success, and a number of similar castings were to be made for the French Government.

Charge 122, *February* 20.

At 6.30 A.M. initial bath, 1,100 lbs. 7 per. cent. Mn. spiegel.
" " 1,100 lbs. fountains.
" " 1,100 lbs. Bessemer ingot-ends.

All charged at a time, cold, the fountains and ingot-ends on the bottom and the spiegel on top.

At 10.35 this charge was apparently melted.

At 11.00, 440 lbs. Bessemer rail-ends were charged.
At 11.15, 440 lbs. " " "
At 11.35, 440 lbs. " " "
At 12.00, 440 lbs. " " "
At 12.20, 440 lbs. " " "
At 12.45, 440 lbs. " " "
At 1.10, 440 lbs. " " "

At 1.20 the slag was found to be rather dark, with a well-defined black film on the outside.

At 1.25 the first test-disk showed the usual rough edges and three deep cracks, but it bent to a close fold with very little cracking. The metal was judged too soft.

At 1.40, 220 lbs. of 7 per cent. Mn. spiegel were charged, in order to restore the proper amount of carbon to the bath; it was placed cold on the banks, where it gradually melted. This should always be done; if spiegel is dropped in the middle of the bath, it will adhere to the bottom and raise some parts of it to the surface while melting.

At 2.05, 440 lbs. Bessemer rail-ends were charged.

At 2.30, 440 lbs. Bessemer rail-ends were charged.

At 2.45 a test-disk resembled the first one, but when bent double under the steam-hammer it cracked nearly clear across. The corresponding slag was about like the other, excepting that the inside next to the rod was somewhat lighter. These tests were considered right, and the bath was given time to heat.

At 2.55 a slag specimen did not differ essentially from the 2.45 test.

At 3.00, 822 lbs. of special pig were charged—about 11 per cent. of the charge already in the furnace.

At 3.08, the pig being very nearly melted, 125 lbs. of ferro-manganese were thrown in hot. The bath was rabbled, and at 3.10 casting took place.

Two tests, taken while casting, broke with 8 and 5 blows; a whole test-ingot broke under the steam-hammer at the third blow.

The time occupied by the operation was 8 hours 40 minutes.

The whole charge was as follows:

7% spiegel	1,320 lbs., or 15.7%	of	the	whole charge.
Refining materials	6,160 lbs., or 73.1%	"	"	"
Special pig	822 lbs., or 9.8%	"	"	"
Ferro-manganese	125 lbs., or 1.4%	"	"	"
	8,427 lbs. 100.00%			

The following table shows the quantity of the different ingredients introduced with the final additions, and their proportion to the charge as it stood before these additions:

Carbon in special pig	24.66 lbs.,	or 0.42%.
" in ferro-manganese	6.87 lbs.,	
Silicon	37.81 lbs ,	or 0.50%.
Manganese in special pig	28.77 lbs.,	or 1.22%.
" in ferro-manganese	62.50 lbs.,	

The charge was used in casting projectiles for the French navy.

Charge 116, *February* 19.

At 3.20 A.M. initial bath, 1,100 lbs. 7 per cent. Mn. spiegel.
" " 2,222 lbs. fountains.

At 6.45 the whole charge was melted.

At 7.10, 444 lbs. Bessemer rail-ends were charged.

At 7.30, 440 lbs. " " "

At 7.50, 451 lbs. " " "

At 8.10, 440 lbs. " " "

At 8.25, 440 lbs. " " "

At 8.50, 440 lbs. " " "

At 9.10, 440 lbs. " " "

At 9.30, 440 lbs. " " "

At 9.45 the first metal test had the usual appearance, but broke before bending to a close fold. It was judged too hard. The corresponding slag test was a little darker than it should have been.

At 9.50, 440 lbs. of Bessemer rail-ends were charged.

At 10.10, 440 lbs. " " "

At 10.30, 440 lbs. " " "

At 10.45 a second test-disk had very rough edges, and there were four well-defined, deep cracks. The disk bent to a close fold, but the crack at the back did not reach half way across. These signs proved the bath to be oxidized, and upon examining the slag it was found to be completely black, but vitreous and clear. It was therefore necessary to add manganese in order to reduce the oxide of iron and bring the bath to a point where the final additions could fulfil their proper functions; 22 lbs. of 50 per cent. Mn. ferro-manganese were thrown in cold, introducing 11 lbs. of metallic manganese, which is the proportion generally used in such cases.

At 11.00 another slag test showed the very dark greenish brown color inside with a black streak outside. No more metal tests were taken.

At 11.06, 895 lbs. of special pig were charged, or about 11 per cent. of the amount previously charged.

At 11.17 the pig was nearly all melted, and 136 lbs. of 50 per cent. Mn. ferro-manganese were thrown in hot. The bath was vigorously rabbled, and at 11.20 casting took place.

The final tests stood respectively 6, 11, and 20 blows of the hammer before breaking; but the permanent bend was in no case more than half an inch. The metal was judged hard

enough for projectiles, as its tendency to softness was not so strong that it could not be remedied by annealing at the proper temperature.

The time of the charge was 11 hours, and the composition was as follows:

7% spiegel	1,100 lbs., or	11.9% of the whole charge.			
Refining materials	7,075 lbs., or	76.9%	"	"	"
Special pig	895 lbs., or	9.7%	"	"	"
50% ferro-manganese	136 lbs., or	1.5%	"	"	"
	9,206 lbs.	100.00%			

The final additions introduced the various ingredients in the following quantities and proportions:

Carbon in special pig	26.85 lbs.,	or 0.42%.
" in ferro-manganese	7.48 lbs.,	
Silicon	41.17 lbs.,	or 0.50 %.
Manganese in special pig	31.32 lbs.,	or 1.21%.
" in ferro-manganese	68.00 lbs.,	

All the above charges represent the hardest type of steel likely to be used in castings.

Soft-Steel Charge 157, *February* 27.

At 8.20 A.M. initial bath, 1,100 lbs. of 12 per cent. Mn. spiegel.

This was charged cold and well spread on the bottom.

At 9.30, 471 lbs. of puddled blooms were charged hot.
At 9.55, 440 " " " "
At 10.25, 471 " " " "
At 11.00, 471 " " " "
At 11.35, 440 " " " "
At 12.10, 471 " " " "
At 12.45, 440 " " " "
At 1.15, 471 " " " "
At 1.55, 440 " " " "

At 2.15 the first test-disk showed a tolerably good edge and three radial cracks about ¾ inch deep. When bent to a close fold under the steam-hammer, it cracked half way across; the grain was very much coarser than that of the hard-steel tests. The metal was thought too hard. The corresponding slag test was beginning to deepen in color, and had a decided black streak through the centre.

At 2.25, 471 lbs. of puddled blooms were charged.

At 2.45, 471 " " " "

At 3.00 a second metal disk looked very much like the first, but it bent to a close fold without cracking in the least; and it even bent fourfold without tearing apart, but there was a deep crack in the centre. The grain was strong, and the fracture was torn and not short. The metal was now judged soft enough. The corresponding slag test was darker than the first, with a black streak running ⅓ of the thickness of the specimen.

At 3.30 another slag test was very dark, with thin, lighter lines running through it.

At 3.42, 220 lbs. of the special pig for soft steel were added. This was about 3½ per cent. of the charge already in the furnace. As it was not necessary to have a large proportion of manganese in the finished product, no ferro-manganese was added, and, after the bath had been thoroughly rabbled, casting took place at 3.50.

The final tests hammered into perfect disks, which bent without cracking until the folds were about half an inch apart. When brought to a close fold under the steam-hammer, they cracked clear across without breaking asunder. It required 8 blows of the steam-hammer to start the test ingot, and, although it cracked in three places, the pieces hung together so that it was impossible to tear them apart by hand.

The time of the charge was 7 hours 30 min., and its composition was:

12% spiegel	1,100 lbs., or	17.2% of the whole charge.
Refining material	5,057 lbs., or	79.4 " " "
Special pig	220 lbs., or	3.4 " " "
	6,377	100.00

The special pig introduced the different ingredients in the following quantities and proportions:

Carbon	3.52 lbs., or	0.057%
Silicon	16.50 lbs., or	0.267%
Manganese	30.80 lbs., or	0.500%

There probably remained in the bath just before charging the special pig between 0.15 and 0.20 of carbon, hardly any

silicon, and not more than 0.15 of manganese. After the reaction had taken place, the finished product would probably have shown a chemical composition similar to that of the soft steel in the large appended table.

In this charge only 3½ per cent. of special pig was used, and no ferro-manganese, in order to obtain the softest metal possible. If a harder shade is desired, four per cent. of special pig should be used; and an amount of ferro-manganese depending upon the degree of toughness required in the finished product. It is obviously possible and easy, by varying the proportion of the ingredients, to change the qualities of the metal; but care should be taken lest too much silicon remains in the bath; 0.40 per cent. seems to be a limit—a larger quantity would tend to decrease the ductility and elasticity of the product. The large appended table, in which a number of charges are noted in detail—their composition, analyses, and physical tests—clearly shows what the final additions should be for each kind of product.

OPERATION IN THE BESSEMER CONVERTER.

This manufacture of steel without blow-holes has never been tried in the Bessemer converter, but a method is indicated by which it could undoubtedly be successfully carried on. The use of iron very highly charged with manganese would cause an objectionably high temperature and much slopping; the amount of manganese must, therefore, be so regulated that a practicable quantity of scrap or blooms thrown into the converter during the blow will keep down the heat. At the same time there must be manganese enough present to furnish food for the oxygen, so that little or no oxide of iron shall remain in the bath when the time comes for the final additions. Tests as above described would be taken from time to time by turning down the converter; when they were right the special pig and the ferro-manganese would be put into the ladle, hot or in a melted state, just before the contents of the converter were emptied in. The charge would thus get a thorough stirring, equivalent to the rabbling in the open-hearth operation.

Many suggestions regarding the operation in the Bessemer converter will occur to the expert, and it is probable that careful trials, accompanied by complete analyses, would enable a skilful operator to work successfully, especially in the production of hard steels.

OPERATION IN CRUCIBLES.

This has not been tried as yet, but it is difficult to see why it should not be successfully performed. The main objection to the crucible practice is its costliness. It would certainly demand less care and watching than the open-hearth operation. When the crucibles are charged and covered, the metal is out of the reach of oxidation, and by pouring the final additions into the ladle just before teeming, a thorough incorporation would be secured. The facility with which the composition of the charge could be varied in the crucible would be very important in some cases, when, for instance, a metal containing an extreme quantity of carbon or of manganese was wanted; these ingredients could be initially charged in definite proportion without fear of further disturbance during the operation. But, from an economical standpoint, the open-hearth process seems to offer advantages over all others for the manufacture of sound steel castings.

THEORY OF THE PROCESS.

We are now prepared to review the chemical reactions which take place at different periods of the operation. It has recently become well known that blow-holes in steel ingots are filled with carbonic oxide produced by the reaction of oxide of iron on the carbon, according to the formula:

$$Fe^3O^4+C=3FeO+CO.$$

During the cooling period the solubility of the carbonic oxide diffused through the metal rapidly diminishes, and some gas-bubbles remain imprisoned in the solidified mass. The problem is, therefore, how shall the production of carbonic oxide be prevented just previous to casting? This problem seemed, as mentioned above, to have been solved by some

English and German manufacturers—Krupp among others—who for the past ten or fifteen years have exhibited large, sound ingots weighing up to 45 tons. An analysis of these steels shows them to be highly carburized and siliconized; they contained sometimes as high as 0.40 per cent. of the latter ingredient. To find an explanation of this result it is necessary to go back to the theory of the Bessemer process. It is well known that during the first period of the operation the combustion of silicon takes place, and that there is then little or no flame, but chiefly sparks; no carbonic oxide is formed in the presence of the more oxidizable silicon. In the same manner silicon decomposes carbonic oxide.

$$Si+3CO=SiO^3+3C.$$

Silica and carbon are thus the only products of the reaction; the carbon set free is dissolved in the metal and the silica goes into slag.

The action of silicon is thus well defined, and although the method of producing sound castings in England and Germany has been usually held as a secret (although Mr. Bessemer early discovered and published it), we may safely presume that such castings are obtained by the addition of silicious pig before teeming. But if these steels are without blow-holes, they are by no means adapted to most purposes. The pig obtainable before special pig was made was relatively poor in silicon, and, in order to be sure that it would act effectively, a rather large quantity had to be charged. This produced a highly carburized and brittle steel, which also showed the bad effects heretofore attributed to silicon, but more properly ascribable to silica.[1]

The influence of silicon on the mechanical qualities of steel has not until lately been very clearly ascertained. To its presence, in some Bessemer steels especially, has been attributed a peculiar red-shortness and cold-shortness. A series of experiments made by the late Wenzel Mrazek, of the School of Mines at Przibram (Bohemia), proved that if a certain quantity of good metallic silicon is added to a pure iron, the original qualities are not changed. He also showed that the action attributed to this ingredient should be ascribed to

silicate of iron. The silica formed by the burning of silicon is changed into silicate of iron, and this silicate, being but slightly fluid, remains mixed throughout the mass of metal and makes it both red-short and cold-short.

At Terrenoire this defect was remedied by using the triple compound of iron, silicon, and manganese at the time and in the proportions mentioned above. The action may be described as follows:

The silicon prevents blow-holes by decomposing the carbonic oxide. The manganese reduces the oxide of iron, and prevents a further production of gases by the reaction of this oxide on the carbon. But the decomposition of carbonic oxide by silicon produces silica, and afterwards silicate of iron, which remains incorporated in the steel; the manganese allows the formation of a double silicate of iron and manganese, which, being much more fusible, readily passes into the slag. The metal is thus purified and remains uninjured by interposed oxide of iron and slag.

In order to show plainly the structural difference between steels without blow-holes obtained by silicon alone and those obtained by an alloy of silicon and manganese, M. Pourcel, the Chief Engineer of the Terrenoire Steel-Works, makes the following experiment: In a porcelain tube he places two receptacles, one holding steel by silicon alone, and the other steel by silicon and manganese; a current of chlorine is passed through them until all the iron is removed in a state of chloride. In the first receptacle there remains a network of silicate of iron preserving the original form of the piece, while in the other there is no residuum.

The analysis of the steel we are considering shows that a considerable proportion of manganese and silicon remains in the final product. There is no doubt that these ingredients impart to the metal some special qualities. It is therefore necessary to conduct the operation in such a manner that the chemical composition of the charge may be absolutely known. This is the reason why it is indispensable to keep oxidation under control during the whole operation, so that the materials forming the final additions will perform their desired func-

tions in the bath, part of the ingredients being absorbed by the reactions, while the rest remain in the finished product. Should the charge become too much oxidized, it would be impossible to ascertain the exact amount of silicon and manganese required to produce the reactions, and the composition might be so changed as to make it unfit for the uses to which it is to be applied. This point has been reiterated because it is of the highest importance.

MOULDS AND CASTING.

The rapid cooling and large shrinkage of steel require great care in the preparation of moulds, and especially of yielding cores. If steel tends to lie as dead and solid as cast iron—and this steel does so—it is nevertheless possible to mould shapes and to pour steel in such a way that the castings will be unsound. Moulds that are damp, or that are otherwise so composed that they may generate gases when they receive white-hot steel, will be likely to cause blow-holes.

The making of moulds for steel has been brought to great perfection in Sheffield and in other places in England, notably at the West Cumberland Works, where Bessemer steel castings are made quite as smooth as ordinary iron castings. But, as before remarked, these beautiful castings are not sound when they are soft and tough.

It is a somewhat remarkable fact that the art of moulding for steel is to a great extent a secret among the English moulders. In many cases the managers and proprietors of works know only in a very general way the proportions of materials employed, just as in many English rolling-mills the management has no drawings nor templets of roll-grooves—these are the private property of the roll-turner. The old Repie moulding mixture, in which steel castings were first made with even approximate success, consisted of calcined fire-clay with just enough raw clay to make it stick together. Old clay pots are now largely used in the place of specially calcined clay, and the mixture is made slightly open and porous by coke-dust, and very refractory Ceylon graphite is often added. The whole is ground fine and passed through a sieve.

The facing is a very important matter. In several works this consists of Ceylon graphite and a little china clay. After long experience, expert moulders have learned to vary the composition and thickness of moulds to suit all thicknesses of castings and grades of steel. The above facts are known generally; each works has its peculiar treatment, and any works can secure a good moulder or can perfect a system with a little experimenting.

At Terrenoire the whole practice has until recently been the casting of projectiles and simple forms in iron moulds; and while hardly the average skill has been attained in mineral moulding, many uniformly solid and fairly smooth complex castings have been produced. The car-wheels, frogs, roll-pinions, bolsters, and other machinery used in the works are now cast entirely in steel. The gun-carriage brace before mentioned was cast in a mould made of ground-clay pots with graphite facing.

The cast iron moulds used in the manufacture of projectiles are made in two superposed sections; the lower section contains the point or rounded part; the upper one the cylindrical part. The use of metallic moulds, besides favoring rapid cooling, which improves the metal by stopping in some degree its tendency to crystallize in large and irregular crystals, forms part of an improved system of feeding the enormous shrinkage of cast steel. Just before casting, a loam-lined fountain, capable of holding from ¼ to ⅓ in weight of the piece in the mould, is placed *hot* in its proper position, then both the mould and the fountain are filled. The metal in the mould cools rapidly on the outside; this cooling spreads by degrees throughout the mass from outside to inside; the solidified particles draw away from the centre, and shrinkage takes place chiefly in the centre of the casting, which will thus tend to become porous—in other words, it will pipe. But the large fountain being thicker and hotter than the mould, the metal it contains will remain liquid, and, flowing down, will gradually feed the shrinkage in the casting. It is well in all cases to make the neck of the fountain or sprue as wide as possible; for if it is too narrow, the metal might set in it and

prevent any further feeding. The sprue for a 10-in. projectile is 16 in. high and 6½ in. in least diameter. Some 5,000 tons of projectiles had been made in this manner up to last winter, with uniformly good results.

This system of a rapidly-cooling mould and a hot sprue or fountain—possibly to be kept hot (for large castings) by means of a bath of liquid iron or other intense and maintained source of heat—is deemed of very great importance by the Terrenoire engineers. They were experimenting on very heavy iron moulds for cannon when we were at the works, and they have. since cast cannon with entire success. I am promised details of the moulds and casting appliances and practice for cannon. Two 18-ton furnaces were also building; they have recently been started, and 15-ton castings have been made; a 28-ton ingot of soft steel for a 3-throw crank-shaft has been cast out of the two furnaces.

ANNEALING.

A glance at Table A will show the important influence annealing exerts on this metal. It will be seen that it not only increases the strength within and beyond the elastic limit, but that it also improves ductility in a notable degree. The average elongation of raw, hard metal is 2.4 per cent., while the same metal annealed stretches 8 per cent. The difference is still more marked in medium steel; the average stretch of the raw material is 2.7 per cent.; the annealed reaches 14.6 per cent., or more than five times the original ductility. This result is due to a change in the crystalline state which is characteristic of all ingot metals. In this state the structure is loose; each crystal is an independent mass easily detached from its neighbor, and the metal is reduced to its minimum strength and elasticity. In ordinary steel, rolling or hammering will not only close the blow-holes, but it will change the crystallization. In the Terrenoire solid steel, annealing at the proper temperature imparts all the qualities due to rolling or hammering ordinary steel. Repeated and careful experiments of the most exhaustive character, made at Terrenoire, have established this fact beyond a doubt. Further

proof is found in a paper on the "Structure of Steel," by M. Chernoff (Chief Engineer of the Abouchoff Steel-Works in Russia), published July 7, 1876, in *Engineering*. It relates to a series of experiments made at these works, among them the following: A coarse-grained, sound cast-steel ingot was cut lengthwise in four parts. One of the quarters was cut, in a lathe, into a test bar; the second was heated to a bright red, forged under a steam-hammer, the forging being stopped whilst the piece was yet rather hot (probably cherry-red); the third piece was heated up to the point at which the hammering of the preceding piece had been left off, and was allowed to cool slowly. The fracture showed a very fine grain, similar to that of the forged piece. These two quarters were also turned into test bars.

The results of the tensile tests were as follows:

	Breaking Load.	Elongation.	Dynamic Resistance.*
Unforged..........	34.8	0.023	0.8
Forged............	41.5	0.053	1.1
Annealed..........	38.7	0.166	3.21

The obvious conclusion is that it is possible to make a steel in its cast state just as strong as if it had been hammered, provided, however, that the metal is regularly without blowholes.

The temperature at which annealing should take place is a good cherry-red; if the temperature is too high, the crystalline structure remains, and with it the lack of strength. The heating should be very gradual, and cooling must be carefully conducted, so as to avoid internal strains. If the final metal tests have proved that a charge is rather hard, the pieces must remain longer in the annealing furnace.

When pieces have to be turned and finished, they should be first roughed down and then annealed; the final shape may be given afterwards. Projectiles, after annealing, are hardened by heating them to a cherry-red and plunging them into oil.

* Dynamic resistance per cubic inch in tons. Ultimate strength x½ elongation.

The specific gravity of the annealed metal is 7.9—above that of ordinary forged steel, which rarely reaches 7.821.

USES OF SOLID STEEL CASTINGS.

The superiority of this steel, as compared with all other materials, for projectiles, has been referred to. The results of the very first experiments in casting cannon were still more remarkable. During the last summer a gun-tube was cast from this metal; it had 8-in. exterior diameter and a 5-in. bore, so that the walls were but 1½ in. thick. The casting was simply bored, annealed, and tempered in oil. Some specimens cut perpendicularly to the axis of the tube were tested August 17 by Col. Maillard, the director of the National Gun Factory at Nevers, with the following results:

	Limit of Elasticity. Tons per Square Inch.	Tension at Rupture. Tons per Square Inch.	Elongation. Per cent.
At the back........No. 1	22.0	42.5	11.1
" ... .No. 2	22.2	39.6	8.7
In front...........No. 1	22.5	38.1	15.1
" ....No. 2	22.7	38.5	15.0

Several pieces 1¼ in. square and 6 in. long were next submitted to the shock of a drop weighing 40 lbs., falling from increasing heights. The supports were 5 in. apart, and rested on an anvil weighing 1,800 lbs. These pieces resisted well, and one of them did not break when the ball fell from 8 ft. in height, which gave it a bend in the centre of about 1 in.

The French Government have specified the following for the trials of all steel tubes for the navy:

	Tons per Square Inch.
Limit of elasticity......................	21
Tension at rupture......................	38

It will be seen from the above that the Terrenoire tube answered more than the requirements. For the experiments with powder the tube was mounted on a portable carriage, after having been placed in a suitable trunnion-ring.

Twenty shots were first fired with the ordinary service charge of 9 lbs. of powder and a 40-lb. shell; after this, 10 shots with a shell weighing 47 lbs., and from this time forward the charges of powder were successively increased by ¼ lb. every ten shots, the shell remaining the same until the 100th. shot was fired. At this point the chamber was quite full, and the charge had to be rammed in order to get it into place, and much difficulty was found in closing the gun. The experiment was stopped at this point, as the official regulation test had been accomplished. After each 10 shots the tube was washed out with care, and measured by means of precise instruments in every part. No flaw of any kind was discovered, and the deformation of the chamber was found to be less than half the average in forged-steel tubes.

Larger tubes will be submitted to trial very shortly; two of them will have an internal diameter of 4 in. only. One has been cast of 13½ in. outside diameter for a gun the body of which will be made of cast steel and will weigh 19 tons. As the central tube is the more delicate portion of the cannon, there is little doubt of success in casting the body of a "built-up" gun also of steel.

It should appear, judging from the general character of this steel as shown in the final table, added to the results of this gun experiment—which is but one experiment, and hence may not be considered conclusive—that the American system of cheap ordnance—cheap because it is cast—is to be successfully realized. If so, it will follow that the just criticism upon the standard American gun, that it is comparatively worthless because it is cast *iron*, will be reversed. We can hardly conceive a fact of greater magnitude—from a defensive point of view—than this: that while the United States has at this moment not a single standard type of naval gun, or gun of position, that is comparable in efficiency with the guns of foreign states, it has, by means of the good policy of its Ordnance Department, studied the results of foreign experiments and avoided the enormous cost of original investigations; and that this policy must now be rewarded by the establishment of the *cheap cast gun*, the metal to be, not crude iron, but steel

having three or four times the strength, as made according to the specification detailed in the foregoing pages. And although we have good field guns, the sound-casting system will be equally applicable for this purpose also, in view of its economy.

The protection of the whole coast of the United States (greater than that of any other Power) and its entire interior defences, heretofore quite inadequate as compared with the protection which steel ordnance provides for other countries—this whole problem may now be solved by the perfection of the art of solid-steel casting, if, indeed, this art does not raise the standard while it largely reduces the cost of armament.

In 1865 the cost of heavy guns was as follows:

Armstrong....	10.5 in. wrought-iron hoop-gun.......	33.6	cents per lb.
Krupp	15-in. solid steel gun.................	87.5	"
Blakely.......	10-in. steel-tube, hooped with steel....	78.5	"
Whitworth....	7-in. " " "	62.5	"
Parrott.......	10-in. cast-iron, hooped with wrought iron.............................	17.0	"
Rodman......	10-in. cast iron.......................	9.75	"
"	15-in. "	13.2	"

The present cost of guns is largely reduced, but the above relative costs will hold good, and they show the very notable comparative cheapness of the cast gun. The exact cost of solid cast-steel guns cannot yet be exactly estimated, but it is certain that it will not exceed one-third of the cost of hammered-steel guns.

With reference to general machinery, it must be obvious that a metal simply cast into usable form, and having the range of tensile strength from 50 to 30 tons per square inch, and the corresponding elongation of 7 per cent. to 28 per cent.,* is destined to replace not only iron castings, but iron and steel forgings which are several times more costly and no stronger.

The hammering of a large mass of steel—for instance, a 40-ton ingot for a gun or a marine shaft—is a very costly and

* It should be remembered that the test specimens of this steel are 4 inches long, while the reported tests of Whitworth's compressed steel are made on 2-inch lengths, and its 30 per cent. elongation would be considerably reduced if tested on 4-inch lengths.

hazardous undertaking. There are but few, if any, hammers in the world which can condense such a mass to the core. The hammer and the special tools are enormously expensive; the new 60-ton hammer plant at Creusôt will have cost above half a million dollars. The heating—several days for a single heat—and the loss by oxidation, and the wasters due to cracking from inadequate or over heating, are important elements of cost. Forging, under the heaviest hammers, reaches only the parts in the immediate vicinity of impact; the piece is therefore subjected to a series of internal strains, due to the difference in the molecular arrangement of adjacent parts. Even in the finished piece the same difference in molecular structure exists. Each part does not receive exactly the same reduction, and crystallization is not equally changed throughout the mass. It is thus left subject to internal strains which may cause ruptures when and where least expected.

The casting of a piece which has the desired shape and requires no reheating beyond a slow annealing, is so great a progress, that it must be obvious to all practical men, especially when it is considered that the product possesses, in every part of its homogeneous mass, all the physical qualities of forged steel.

This metal must therefore come into use for all heavy parts of machinery—for shafts, screws, cranks, bed-plates, hydraulic cylinders, pinions, frames, gearing, etc., etc. For rolling-mills its use is clearly pointed out; its wearing capacity is immensely greater than that of cast iron, and its high tenacity ensures stability under sudden strains. Housings, rolls, pinions, boxes, riders, and, in fact, almost every part of a train, could be advantageously made of this metal; and, although the first cost might be larger than that of an ordinary plant, the economy in repairs and maintenance would soon prove a compensation.

Railroad engineers will find this metal adapted to many uses within their province. Frogs, crossings, car-wheels, driving-wheels, cranks, axles, and parts of framing can be, made of it, with economy in weight and increase of duration.

The softest grades of this metal, say 30 tons per sq. in.

with 30 per cent. elongation, seem eminently fitted for the manufacture of armor-plates for ships and forts. The late Italian experiments on plates of steel of this grade *versus* iron have already proved the superiority of steel. The advantages are numerous. The plates can be cast so as to conform to the shape of the ship; they can be made hollow, having a space, which recent experiments have proved most useful, between the inside and outside walls, and bolt-heads and other modes of attachment to the hull can be concealed. Besides this, the plates can be made of unlimited thickness.

The use of steel in construction has so far been greatly hampered by the difficulty of bringing it to its final shape. Its behavior is so unlike that of iron that workmen have to be specially educated to manipulate it. The building of steel ships in the French dock-yards, as described in detail by M. Barba,* proves that rolled and hammered pieces must be repeatedly annealed during the operations of manufacture. On account of its hardness, several reheatings, with their accompanying waste and risk, are necessary to bring steel into difficult rolled shapes, such as I-beams. These embarrassments are obviously remedied by casting the metal at once into the desired shape.

This steel is readily welded, on account of its large percentage of silicon, which in oxidizing makes an ever and intimately present flux. The advantages of welding a casting to a rolled or forged bar will be appreciated by machine-builders.

It seems eminently proper, before closing this monograph, to mention with praise the gentlemen who have developed the remarkable process which we have described, and, in so doing, to state again the grounds of its novelty, which they have, with so much painstaking experiment, developed and perfected.

It is true that steel castings have been previously made which have possessed some, but not all, of the physical characters which the Terrenoire solid-cast steel embodies. These other steels have not, for instance, combined softness with

* Translation published by Van Nostrand, New York.

soundness; they have not been both hard and malleable; and they have not possessed a high specific gravity. Even where these previous castings are found to contain silicon or manganese, or both, these ingredients have occurred in different proportions from those used at Terrenoire. Some years of experimenting prove that, without the reduced oxidation of the bath, and without the final addition of silicon and manganese in substantially the proportions described, a cast metal possessing the physical qualities described cannot be produced. The Terrenoire process is thus novel in the following particulars: 1st. It employs manganese and silicon in definite proportions and in a combination for definite purposes. 2d. It employs them at regulated times during the operation, in order that the reactions which have been mentioned may occur. The invention is, therefore, not a modification of any previous accidental use of silicon and manganese at indefinite times, but it is a consecutive system of times and amounts of application of these ingredients, to bring about results not heretofore known, sought, or realized.

The development of this most remarkable and truly scientific manufacture has been due to the combined efforts of Mr. Valton, an eminent metallurgist (who proved himself to be a discriminating judge at our Centennial Exhibition*); of Mr. Euverte, the General Manager of the Terrenoire Works, who had such a correct technical knowledge of iron metallurgy that he not only allowed the Company's money to flow for years into the preliminary experiments, but that he contributed to the technical result; and, I believe, chiefly of Mr. Pourcel, the Chief-Engineer of the Terrenoire Works, whose thorough training in investigations concerning the chemical and physical properties of steel, and whose enthusiasm, which was never checked by the discouraging results of early experiments, not to speak of the special adaptation of his mind to metallurgical research, have eminently qualified him to conduct and to perfect the remarkable product which in France is known as *acier sans soufflures*.

* See his official report to the French Government.

INGREDIENTS, ANALYSES, AND MECHANICAL TESTS OF SOLID STEEL CASTINGS.

Number of the charg's.	Materials forming the charge—Pounds.							Number of hammer-blows necessary to break a test-piece of hammered metal.	Percentage of ingredients introduced, with the final additions.			Chemical analyses made on the product before annealing.			Tensile Tests.—Length of test-bars=4 in. Section=0.232 sq. in.								Drop-tests on annealed metal
															Annealed metal.				Metal heated to cherry-red and cooled in oil.				
	Spiegel, 7 to 8 per ct. Mn.	Bessemer rail-ends.	Soft-steel borings	Puddled iron.	Special pig.	Ferro-manganese.			Mn.	C.	Si.	Mn.	C.	Si.	L.	B.	C.	E.	L.	B.	C.	E.	
*1996	500	4400			540	100 52% Mn.	Hard metal for projectiles.	4–1	1.30	0.408	0.415				23.65	47.30		8.00					6 ft. $4\frac{3}{4}$ in.
*2004	500	5200			620	90 “		3–2	1.05	0.380	0.410				23.24	47.94		8.75					6 ft. $10\frac{3}{4}$ in.
*2007	500	4400			540	100 “		6–7–8	1.30	0.408	0.415	Average analysis:			23.17	45.08		7.50					6 ft. $4\frac{3}{4}$ in.
2035	700	4600			600	108 “		4–4	1.31	0.415	0.425	0.945	0.560	0.340	24.32	46.03		6.20	26.03	50.29		5.60	6 ft. $4\frac{3}{4}$ in.
2038	700	4400			560	100 “		4–2	1.265	0.403	0.412				22.98	46.03		4.00	26.03	53.97		6.80	6 ft. $2\frac{3}{4}$ in.
*2051	700	4800			594	108 “		5–11	1.26	0.403	0.410				22.98	46.35		13.00	22.98	50.41		12.20	7 ft. $8\frac{3}{4}$ in.
*2071	600	4400			600	90 “		2–13	1.215	0.420	0.445				21.27	46.35		10.00					7 ft. $0\frac{3}{4}$ in.
*2074	600	4400			600	88 “		16–9	1.215	0.420	0.445				21.27	46.35		10.80					6 ft. $8\frac{3}{4}$ in.
2112	700	4000			564	86 “		3–3	1.25	0.425	0.448				21.27	48.38		9.00	29.90	52.70		7.30	6 ft. $8\frac{3}{4}$ in.
*2124	600	4400			600	106 “		4–3	1.18	0.415	0.450				22.98	48.38		11.50	30.34	57.15		5.50	7 ft. $0\frac{3}{4}$ in.
2130	700	5200			708	106 “		5–4–9–6	1.21	0.417	0.448				23.17	50.80		7.70	29.27	56.38		7.80	6 ft. $8\frac{3}{4}$ in.
2138	500	4400			588	90 “		7–1	1.22	0.418	0.448	Average analysis:			22.86	50.48		11.30	27.94	50.80		8.40	7 ft. $10\frac{3}{4}$ in.
2145	500	4400			588	88 “		2–2	1.21	0.416	0.448	0.880	0.500	0.390	21.59	47.94		9.30	29.71	53.34		7.00	6 ft. $10\frac{3}{4}$ in.
2168	500	4400			588	86 “		8–5	1.19	0.415	0.448				22.86	49.53		7.90	26.03	50.67		7.50	6 ft. $6\frac{3}{4}$ in.
2179	500	4000			540	80 “		5–5	1.175	0.417	0.448				21.52	44.45		8.10	26.67	47.75		7.00	6 ft. $6\frac{3}{4}$ in.
2230	800	5214			720	104 “		6–7	1.175	0.414	0.448				21.09	47.75		11.50					6 ft. $8\frac{3}{4}$ in.
2237	500	4080	830		672	94 “		8–4	1.115	0.425	0.462				22.86	50.03		7.60					6 ft. $8\frac{3}{4}$ in.
2259	800	5200			720	112 “		9–4	1.24	0.420	0.450				22.86	50.48		7.50					6 ft. $8\frac{3}{4}$ in.
	Spiegel 12 per ct. Mn.																						Not broken, at
2078	400		1400	1200	126		Soft metal.	Bent.	6.30	0.0725	0.340	0.420	Average =0.180	0.203	14.73	31.24	45.00	28.50	24.25	39.43	35.00	15.00	8 ft. $2\frac{3}{4}$ in.
2081	400		1400	1200	120	14 77% Mn.		“	8.35	0.0885	0.290	0.660		0.263	17.00	32.38	43.50	25.60					“ “
2149	400		2000	1600	160	13 “		“	8.10	0.0835	0.300	0.610		0.233	12.70	29.00		26.70	18.79	38.10		19.50	“ “
2208	580		1000	2010	144	13 “		“	8.40	0.0860	0.300	0.630		0.209	15.11	31.94		24.30	20.00	34.98		16.00	“ “

OBSERVATIONS.

FIRST SERIES.—*Proportion in weight* of materials introduced at the end of the operation:

Special pig=11 per cent. of the charge already in the furnace.

Metallic manganese=1.3 per cent. of the whole charge, including special pig. This proportion of metallic manganese consists partly of the manganese contained in special pig and of a supplementary quantity introduced in the shape of 52% ferro-manganese.

SECOND SERIES:

Special pig=12 per cent. of the charge already in the furnace.

Metallic manganese=1.2 per cent. of the whole charge, including special pig, as above.

Special pig used in projectile charges.—Mn.=3.50; C.=3.00; Si.=4.20; P.=0.100.

Special pig used in soft-steel charges.—Mn.=14.00; C.=1.60; Si.=7.50; P.=0.125.

OBSERVATIONS.

L represents the load per square inch (in 2,240-lb. tons) necessary to bring the test bar to its limit of elasticity.

B is the breaking load.

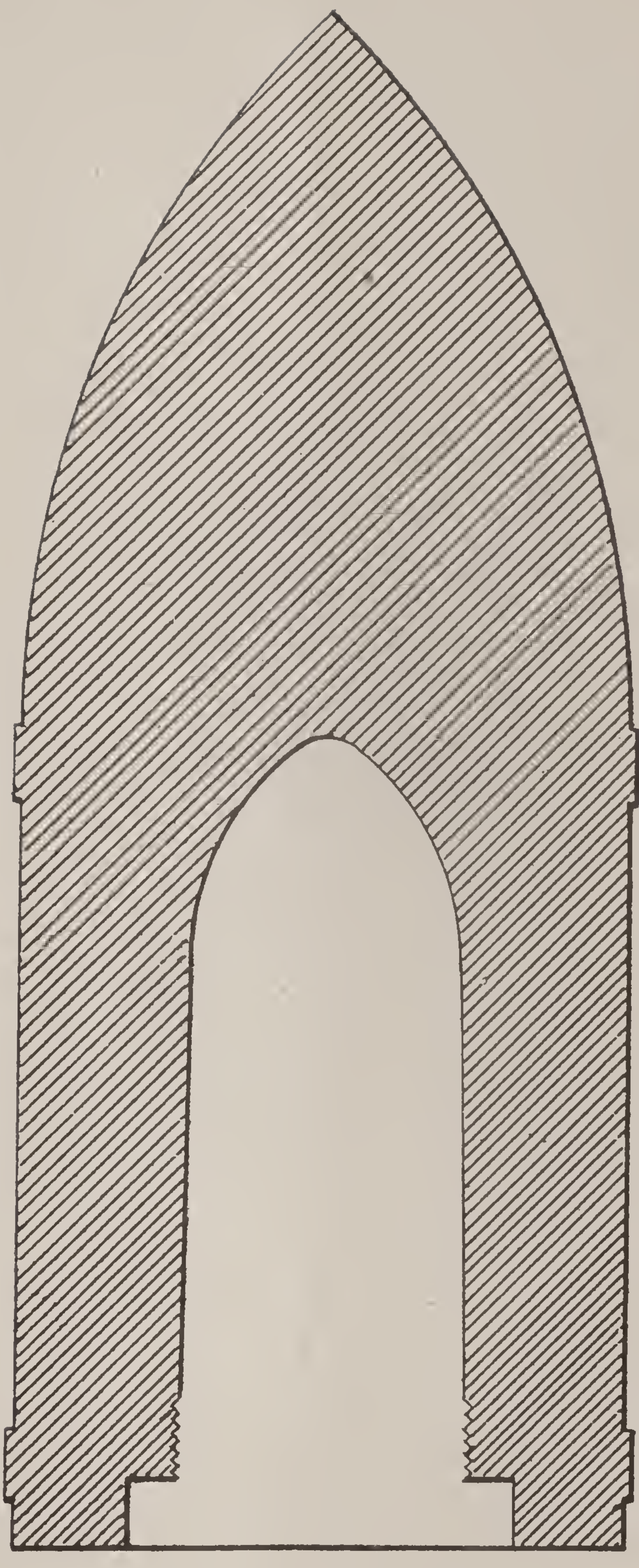
C is the percentage of contraction.

E is the percentage of elongation measured between two points 4 inches apart.

The drop-tests are made with bars $1\frac{3}{16}$ in. square. The bearings are $6\frac{5}{16}$ in. apart. The drop weighs $39\frac{3}{4}$ lbs. This at first falls from a height of 5 ft. $10\frac{3}{4}$ in., and is raised 2 inches higher every time.

10-in. projectiles from charges marked thus * go through an 8-in. armor-plate inclined at 30°, with an original speed of 1,332 ft.

Also, through an $8\frac{11}{16}$ in. armor-plate inclined at 20°, with original speed of 1,394 ft.



Scale of Inches.

0 1 2 3 4 5 6 9 12 15 18